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Mat. Res. Soc. Symp. Proc. Vol. 674 © 2001 Materials Research Society

Super-Resolution Readout for Magneto-Optical Disk by Optimizing the Deposition Condition of Non-Magnetic Mask Layer

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ABSTRACT

Super-resolution near-field structure (Super-RENS) was prepared by a heliconwave-plasma sputtering method to improve the disk property that is combined with a magneto-optical (MO) recording disk. Antimony and silver-oxide mask layers were prepared by the method and refractive indices were measured. Recording and retrieving of signals beyond the resolution limit (<370 nm) were achieved for both mask cases. Attempts to optimize the disk structure were also made using a conventional sputtering method. The smallest mark size was around 200 nm and the highest carrier-to-noise ratio (CNR) was 30 dB for 300-nm mark and 22 dB for 250-nm, when using a laser wavelength of 780 nm and a numerical aperture of 0.53. We have found that there is a competing super-resolutional mechanism besides Super-RENS that appears when high readout laser power is applied. This mechanism played rather an important role at least in the mark-size range of 200-370 nm.

INTRODUCTION

Tominaga et al. have proposed a technique called Super-RENS (super-resolutional near-field structure) and described that it is one of the promising for high-density optical recording and readout [1]. Super-RENS consists of a mask layer sandwiched by dielectric layers. Antimony (Sb) [1] and silver oxide (AgOx) [2] have been used for the mask layer and are expected to work as an optically transparent aperture (TA) and a light scattering center (LSC), respectively, by focusing the laser beam. When Super-RENS and a phase-change (PC) disk is combined and the distance between the mask and recording layer is controlled in shorter than ~50 nm, small marks beyond the optical resolution limit can be successfully recorded and retrieved. Kim et al. have recently combined the technique with magneto-optical (MO) recording layer and obtained super-resolutional readout with LSC-type [3]. However, the smallest mark size was around 200 nm and it is still much larger than 60 nm in PC case [4]. Further attempts to achieve smaller mark readout and also to improve carrier-to-noise ratio (CNR) are necessary in MO case for the moment.

Two approaches are made to improve the disk property of MO that combines with Super-RENS. One is to make high-quality Super-RENS by using heliconwave-plasma (HWP) sputtering method. HWP sputtering method has the potential to make smooth and dense film, and is used to prepare multi-layer X-ray mirrors and optical devices [5]. In this proceeding, preparation of Super-RENS by the method and an attempt to combine it with MO are described. Another is to optimize the structure mainly by controlling the thickness of each layer. Here just summarizes the results briefly and one should refer to the recent work of Kim et al. in detail [6].

We also discuss on another competing mechanism besides Super-RENS that makes super-resolutional readout possible at least near the optical resolution limit.

EXPERIMENTAL

Both HWP and RF-magnetron sputtering methods were used to prepare films for the disk structure. For HWP sputtering, background pressure of the chamber was kept at the order of 10^{-6} Pa and distances between the substrate and targets were 200 mm. The target RF-power and sputtering pressure were varied in the range of 30-200 W and 0.25-0.8 Pa, respectively. The power for RF-induced coil was fixed at 20 % of the one for the target. For RF-magnetron sputtering, the background pressure of the deposition chamber was at the order of 10^{-4} Pa and the distances were about 40 mm. The sputtering RF-power and pressure were fixed at 200 W and 0.5 Pa, respectively.

Films were deposited on glass substrates for the objectives of film-deposition rate and refractive indices, and on polycarbonate disk substrates to evaluate disk properties. All the films were prepared at room temperature. The film-deposition rate was estimated from the thickness measured by a surface texture measuring system (Sloan Technology, Dektak3) and the sputtering time. Refractive indices were measured by an ellipsometer (Mizojiri Optical Co., DHA-OLX/S4M) at a laser wavelength of 632.8 nm. Raman scattering measurements were performed with a Renishaw Ramanscope using a wavelength of 488 nm, in back-scattering geometry. An X-ray fluorescence spectrometer (Rigaku Corporation, RIX2100) and a vibrating sample magnetometer were used to evaluate on composition ratio and coercivity of the MO layer, respectively. Recording and retrieving of the signals for the prepared disk were carried out using a MO disk drive tester (Nakamichi, OMS-2000) with a wavelength (λ) of 780 nm and a numerical aperture (NA) of 0.53. Details on the disk-evaluation can be found elsewhere [3, 6].

RESULTS

Prior to Super-RENS preparation by HWP sputtering method, Sb and AgOx thin films were directly deposited on glass substrates and their refractive index values were measured. Figure 1 shows the indices change of Sb film as a function of its thickness. Hence, the target RF-power and sputtering pressure were 50 W and 0.4 Pa, respectively. As the thickness increased from 5 to 15 nm, there was a large change on the extinction coefficient k from 3.0 to 5.4. In Raman scattering spectra, a broad peak (~144 cm^{-1}) was observed for 5-nm film and two sharp peaks (114 and 150 cm^{-1}) for 15-nm film, and they correspond to amorphous [7] and crystalline Sb [8], respectively. Thus the increase of k value observed in Fig. 1 derives from an amorphous-to-crystalline transformation [9]. As the thickness further increased above 15 nm, coefficient k decreased when high sputtering pressure (>0.2 Pa) was used [9]. In Raman scattering spectra, two crystalline peaks were observed and there were no evidences of the film being amorphous. Similar decrease of k value can also be recognized when Sb film was prepared by RF magnetron sputtering method, but at much higher sputtering pressure (>1.0 Pa). We believe that the effect of sputtering pressure is more evident in HWP sputtering since the distances between the substrate and targets are long (200 mm) compared to a conventional sputtering method. Furthermore, index of refraction n decreased monotonically from about 4.1 to 2.8 as the thickness is increased and was less dependent on the sputtering pressure. For TA-type Super-RENS, it is necessary to prepare an opaque crystalline Sb film in as-deposited condition [1]. Therefore, the film-thickness

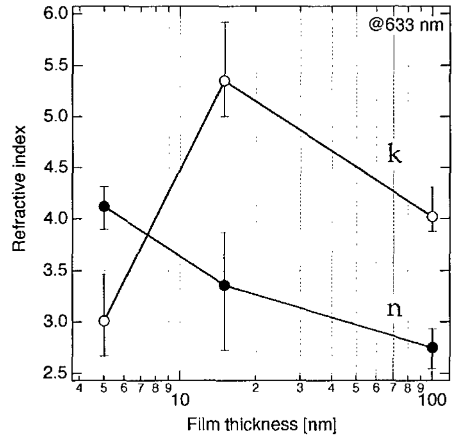

Figure 1. Refractive index of Sb films prepared by the HWP sputtering method as a function of film thickness. Closed circles: index of refraction (n) and open circles: extinction coefficient (k).

should be 15-nm or thick. Also it is preferred to use lower sputtering pressure to avoid any deterioration of the film quality, especially for thick Sb film [9].

Figure 2 shows the indices change of AgOx film as a function of oxygen-gas flow ratio. The target RF-power and sputtering pressure were 100 W and 0.4-0.5 Pa, respectively. As oxygen-ratio is increased, k-value rapidly decreased and became nearly transparent at the ratio higher than 0.25. The result is almost similar to the one made by RF magnetron sputtering [2] and this confirms that AgOx film is successfully made by the HWP sputtering method. Refractive indices

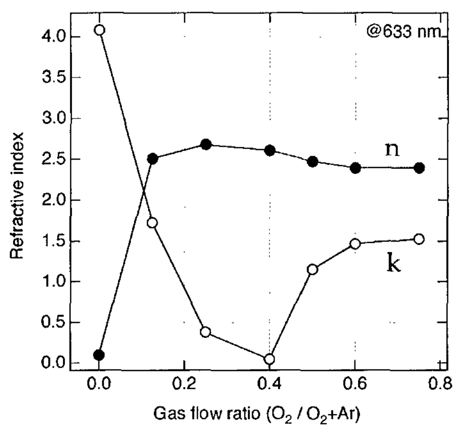

Figure 2. Refractive index of AgOx films prepared by the HWP sputtering method as a function of oxygen gas flow ratio. Closed circles: index of refraction (n) and open circles: extinction coefficient (k).

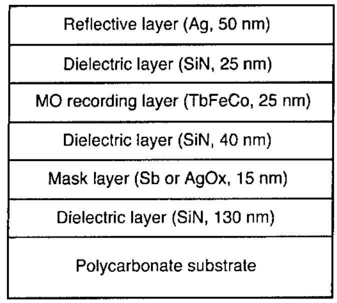

Figure 3. The disk structure with Super-RENS and MO recording layer.

for AgOx were less dependent on the film thickness, as far as we examined. Previous work on LSC-type Super-RENS showed that AgOx film work as a LSC when the oxygen ratio is higher than 0.4 [2]. This may suggest that LSC-type is not restricted to the sputtering condition and can easily be prepared.

Taking above results into consideration, TA- and LSC-type Super-RENS were tentatively made by the HWP sputtering method. A schematic of the disk structure is shown in Figure 3. On polycarbonate disk substrate, Super-RENS (SiN/Sb/SiN or SiN/AgOx/SiN) was first deposited by the HWP sputtering method. Refractive indices of Sb mask was n=3.3 and k=5.2, and of AgOx mask was n=2.4 and k=1.0. MO recording layer (Tb-Fe-Co) and the rest were then deposited by a conventional RF-magnetron sputtering method. Some attempts were made to deposit Tb-Fe-Co layer by the HWP sputtering method, however the effect of sputtering pressure was quite obvious. Composition ratio, refractive index and magnetic property of the film were difficult to be controlled. We here concentrated on preparing Super-RENS by the HWP

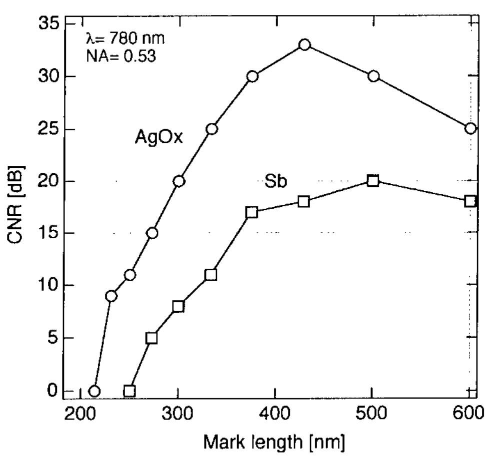

Figure 4. Relationship between mark size and the CNR with different mask layers prepared by the HWP sputtering method. Circles: AgOx and squares: Sb.

sputtering method and MO layer by a well-understood method. Composition ratio of the MO film was Tb 20 at%, Fe 71 at% and Co 9 at%, and the coercivity was about 10 kOe.

Figure 4 shows the relationship between mark size and the CNR of Super-RENS MO disks prepared by HWP and RF magnetron sputtering methods. Resolution limit can be calculated as $\lambda/(4xNA)$, and it is about 370 nm. It is clear in the figure that recording and retrieving of the signals are achieved beyond the limit for both Sb and AgOx cases. For Sb, it was for the first time to observe super-resolutional property when Super-RENS is combined with MO recording layer. For AgOx, the result was similar to the one prepared simply by RF-magnetron sputtering [3] and advantages of using HWP method cannot be well recognized at this moment.

Besides, some attempts to retrieve smaller marks and to obtain high CNR were made by optimizing the disk structure using RF magnetron sputtering method alone. Mark-size limit and CNR were dependent on the preparation condition, however the smallest mark size was always at around 200 nm. One of the highest CNR was 30 dB for 300-nm mark and 22 dB for 250-nm, when AgOx thickness was optimized to 60 nm [6].

DISCUSSION

Super-resolutional property itself was highly reproducible in the experiments we carried out. However, attempts to make high quality Super-RENS or to optimize the structure did not bring a drastic improvement on the super-resolutional properties. We therefore performed additional experiments to understand what is going on in our Super-RENS MO disks. First, Fuji et al. have recently observed recorded marks by magnetic force microscope (MFM) and showed that marks smaller than 180 nm can no longer be identified each other [10]. Thus a CNR drop at around 200-nm mark in Fig. 4 can be explained by the limit on recording of small marks. Second, we have prepared a conventional MO disk and found that super-resolutional property can still be observed by optimizing the laser power for readout. Figure 5 shows the relationship between

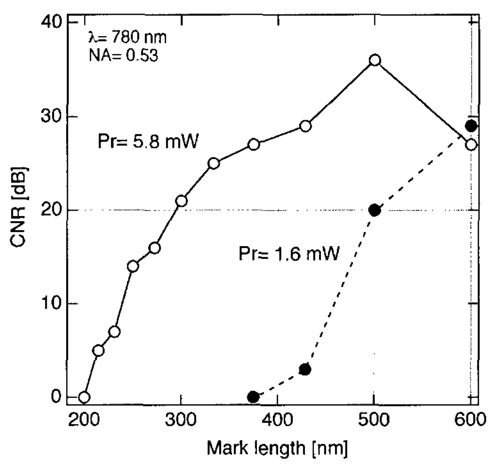

Figure 5. Relationship between mark size and the CNR for a conventional MO disk with different readout power (Pr). Closed circles: 1.6 mW and open circles: 5.8 mW.

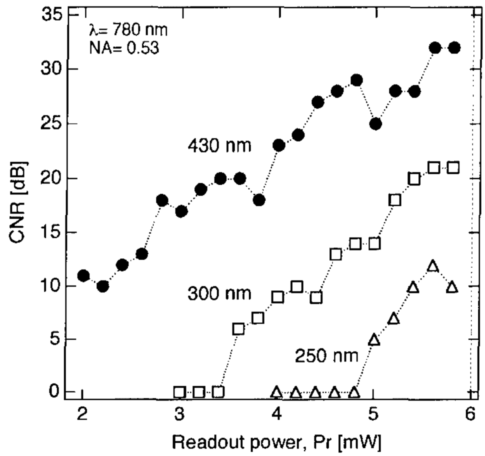

Figure 6. Relationship between readout power (Pr) and the CNR for different mark size. Triangles: 250 nm, squares: 300 nm and closed circles: 430 nm.

mark size and the CNR with a low (1.6 mW) and a high (5.8 mW) readout power. Disk structure is almost similar to the one shown in Fig. 3, but no mask layer was prepared between two dielectric layers. When the readout power is low, CNR became zero at the resolution limit and no super-resolutional property can be found. When the power is raised high, super-resolutional readout can be clearly observed in the mark-size range of 200-370 nm. Figure 6 shows the relationship between readout power and the CNR for different mark sizes of 250, 300 and 430 nm. It was evident that smaller marks appear at higher readout power. The mechanism for this high-power super-resolutional (HP-SR) readout is under investigation [11]. Above 6.0 mW, a recording process started to take place and the CNR rapidly dropped to zero.

Super-RENS also requires a high readout power to create silver LSCs in the mask layer. It is thus difficult to distinguish Super-RENS and HP-SR at this moment when evaluating Super-RENS MO disks. If one assumes that HP-SR mechanism was rather dominant, then it is reasonable that the improvement on the disk property was not well achieved by the modification of Super-RENS. Since CNR property can only be obtained down to 200-nm mark size, our discussions here concentrated on a short range between it and the resolution limit, i.e., 200-370 nm. Silva et al. have shown that silver cluster (~30 nm) works as a probe to image the contrast provided by the MO Kerr effect with high-resolution [12]. This suggests that a combination of LSC-type Super-RENS and MO recording layer is a promising for high-density recording and readout. When Super-RENS mechanism became a dominant one at a certain small mark-size, optimization based on attempts examined here should play more important role. HP-SR mechanism just contributes to improve the CNR at least in the range of 200-370 nm and there is no need to distinguish or to remove for the practical use. As MFM result indicated, it is first necessary to record small marks of ~100 nm in MO layer, and this is probably a key to evaluate the potential of combining Super-RENS and MO recording layer.

CONCLUSIONS

Super-RENS was prepared by HWP sputtering method and combined with MO recording layer. Super-resolutional property can be obtained for both AgOx and Sb mask cases. Improvement on the disk property was not sufficiently achieved here by the use of HWP sputtering and by the attempts to optimize the structure. Smallest mark size stayed at around 200 nm and CNR was 30 dB for 300-nm mark. This was partly explained by the coexistence of different super-resolutional mechanism that appears when high readout laser power is applied, at least in the mark-size range of 200-370 nm. For smaller mark (<200 nm) recording and readout, we found from MFM mark observation that recording property of MO should be first improved and combination with Super-RENS is then expected to play more active part in readout.

ACKNOWLEDGMENTS

Authors are grateful to A. Ohta of ULVAC Japan Ltd., T. Kikukawa of TDK Corp. and K. Ito of National Institute for Materials Science.

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